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Application of MHI CO2 capture technology for exhaust gas from internal combustion engine

Exhaust Gas Aftertreatment Solutions & CCS

takashi kamijo, Mitsubishi Heavy Industries, ltd.

Shinsuke Nakatani, Mitsubishi Heavy Industries, ltd.
Tomoki Noborisato, Mitsubishi Heavy Industries, ltd.

ABSTRACT

Reducing greenhouse gas emissions from sectors that use a lot of energy – such as industrial manufacturing and power generation – is a challenge that will rely on the expertise of highly skilled people around the world. Businesses are using new and innovative ways to deliver the energy the world needs, while also working to transition to a future with net-zero greenhouse gas emissions. Carbon capture and storage on its own is among the few proven technologies that could reduce CO2 emissions from high-emitting and hard to decarbonize sectors.

Mitsubishi Heavy Industries, Ltd. (MHI) has developed the proprietary high-efficient flue gas CO2 capture technology known as the Advanced KM CDR Process™ with Kansai Electric Power Co., Inc. (KEPCO). Sixteen commercial plants with CO2 capacities ranging from 0.3 tons per day to 4,776 tons per day have been constructed around the world, and two plants are under construction as of June 2024. This process efficiently captures CO2 from various facilities, including power plant flue gas, and is contributing to the energy transition. Specifically, MHI demonstrated a very high CO2 capture (over 99%) in a long-term test campaign at the KEPCO / MHI pilot plant and Technology Centre Mongstad (TCM), Norway in 2021. MHI's CO2 capture has been mainly targeting large-capacity emission sources such as power plants and chemical plants. However, CO2 capture from exhaust gases of internal combustion engines such as gas engines and ships has recently also become important as an environmental measure due to the growing need for a decarbonized industry.

Flue gas from internal combustion engines often contains impurities that have a negative effect on the amine solvent. Appropriate pretreatment may be required to ensure the integrity of solvent, and impurities contaminating the captured CO2 may need to be removed by a purification unit. Gas volume, impurities, and conditions may fluctuate drastically during the operation. The CO2 capture system should be able to follow these fluctuations without disrupting its operation.

MHI has begun a study on commercial adaptation and optimization of the Advanced KM CDR process™ to capture CO2 from flue gases from internal combustion engines with high efficiency and reliability while resolving the above issues.

This effort includes the campaign using MHI's CO2MPACT™ mobile testing unit for actual flue gas at of a gas engine unit and a ship. The mobile tests have provided useful outputs that could not be predicted from theoretical studies, such as the accumulation behavior of trace impurities in the exhaust gas in the solvent, solvent degradation, the impact on amine emissions ant others.

This presentation will provide insights into the challenges and specific solutions for capturing CO2 from flue gas from an internal combustion engine in MHI's CO2 capture unit, and explain our activities towards commercialization of the system.

1. Introduction

Amine scrubbing is considered the most mature technology to mitigate the anthropogenic CO_2 emissions from fossil fuel-burned power plants [1].

Mitsubishi Heavy Industries, Ltd. (MHI) developed the proprietary high-efficient flue gas CO_2 capture technology known as the Advanced KM CDR Process™ with the Kansai Electric Power Co., Inc. (KEPCO). Eighteen (18) commercial plants with CO_2 capacities ranging from 0.3 tons per day to 4,776 tons per day have been constructed around the world, and two (2) plants are under construction as of June 2024. This process efficiently captures CO_2 from various facilities, including power plant flue gas, and is contributing to the energy transition.

CO_2 capture from exhaust gases of internal combustion engines is also important as an environmental measure due to the growing need for a decarbonized society. For example, a gas engine is used as distributed power sources and are scattered in large numbers as sources of CO_2 emission. Future demand for this facility can be expected as targets for Carbon Capture and Storage (CCS).

This paper describes the outcome of a mobile test carried out to look for the challenges to commercialisation of CO_2 capture from gas engine flue gases.

2. Consideration for capturing CO_2 from the gas engine

2.1 Anticipated challenges and solutions

Flue gas from the gas engine contains impurities such as SOx, NOx, heavy metal, unburned hydrocarbon, and others that have a negative effect on the amine solvent. Appropriate pretreatment may be required to ensure the integrity of solvent, and impurities contaminating the captured CO_2 may need to be removed by a purification unit. Gas volume, and conditions may fluctuate drastically during the operation. The CO_2 capture system should be able to follow these fluctuations without disrupting its operation.

MHI has been making a study on commercial adaptation and optimization of the Advanced KM CDR process™ to capture CO_2 from flue gases from internal combustion engines with high efficiency and reliability while resolving the above issues. This effort includes the campaign using MHI's CO2MPACT™ mobile testing unit for actual flue gas at of a gas engine unit.

2.2 Mobil test

The mobile test used a small unit called "CO2MPACT™" manufactured by MHI. The capacity is 0.3 tons per day. The absorbent used was KS-21™, MHI's the latest solvent.

This mobile test allows for a commercial evaluation of the effect of trace components in the gas on the solvent and emissions. It also enables a commercial evaluation of the purity of the captured CO_2 and the impurities contained therein. The test was conducted for a period of over 1,000 hours. The operating condition of the mobile unit included not only the steady state but also load fluctuations of up to 26 % per minutes.

Figure 1. CO2MPACT™

Figure 2. Mobile unit

Table 1. Operating condition of mobile test

	Unit	Range		
Flue gas flow rate	Nm^3/h-w	44	-	70
CO_2 concentration	%	5.6	-	6.1
CO_2 capture rate	%	81	-	95
CO_2 capacity	ton/day	0.10	-	0.18

2.3 Characteristic of gas engine flue gas

The flue gas condition is shown as Table 2 below. NO_2 from NOx in the flue gas that accumulates in the solvent as so-called Heat Stable Salts (HSS) was sufficiently removed by DeNOx unit. Hydrocarbon is a typical substance known to cause foaming in the amine solvent.

Lubricating oil supplied to the piston sliding part flows into the combustion chamber and is discharged in the flue gas. The hydrocarbons contained in the flue gas expect to be more unburned hydrocarbons from fuel gas than those from lubricating oil and the effect on the solvent needs to be confirmed. However, the main hydrocarbon contained was methane, which has a low boiling point and low solubility in the amine solvent.

Table 2. Flue gas condition for gas engine

		Engine (18KU30GSI)		Engine (GS16R2)		
		Run 1	Run 2	Design	Run 1	Run 2
Item	Unit	Inlet of DeNOx			Outlet of DeNOx	
Temp.	deg. C	181	167	170	N/A	N/A
Press.	kPaA	101.3	101.3	N/A	N/A	N/A
CO2	vol%-dry	5.2	5.5	6.0	6.1	5.5
CO	ppmd	350	350	396	40	37
O2	vol%-dry	11.6	11.2	10.2	10.5	11.0
N2/Ar	vol%-dry	83.2	83.3	83.8	N/A	N/A
H2O	vol%	10	10	N/A	N/A	N/A
NOx/NO2	ppmd	<90/ N/A	<149/ N/A	<165/ N/A	32/～1.3	26/1
SO2/SO3	ppmd	<1/ N/A	<1/ N/A	<50/ N/A	N/A	N/A
HCHO	ppmd	N/A	N/A	N/A	4.3	4.7
CH3CHO	ppmd	N/A	N/A	N/A	0.1	0.2
VOCs	ppmd	THC=1,700	THC=1,700	THC=1,812	THC=1,400	THC=1,700
NH3	ppmd	N/A	N/A	N/A	0.4	0.6
Methane	ppmd	1,315	1,315	1,698	1,200	1,550
Ethane	ppmd	148	148	N/A	50	87
Propane	ppmd	98	98	N/A	32	41
Butane	ppmd	26	26	N/A	1.8	2.7
Ethlene	ppmd	59	59	N/A	3.3	2.8
Propylene	ppmd	18	18	N/A	<1	<1

N/A: No data available

2.4 Mobile testing campaign result

2.4.1 Amine emission from the absorber

SO_3 leads to generate aerosols in the absorber, causing a sharp increase in amine emission [2]. This phenomena is explained by the fact that the amine vapor present inside the absorber is absorbed into the sulfuric acid mist caused by SO_3. An amine vapor absorption into the mist continues until the amine vapor pressure dissolved in the mist reaches equilibrium with the amine vapor inside the absorber, which is typically at several hundred to several thousand ppm. Thus, the mist containing amines due to SO_3 causes a dramatic increase in amine emissions. In addition, solvent that accumulates degraded compounds and/or impurities from flue gas may accelerate degradation reactions, which may affect amine emission. Amine emissions were measured for solvent with accumulated impurities at the end of the test campaign. The result confirms that the amine emission in the outlet gas of the water washing section of the absorber was relatively low, and that there was no obvious increase in the emission concentration.

2.4.2 Accumulation of impurities and degradation products in solvents

The acidic components of NOx and SOx in flue gas react with the amine solvent to accumulate as HSS. Oxygen in the flue gas causes oxidative degradation of the amine solvent, which in turn increases the HSS of organic acids. Inorganic compound and/or metals in the flue gas may accelerate the degradation of the amine or have a negative impact on operations.

The result of the mobile long-term test shows that the increase in HSS due to NOx and SOx is relatively very low. No adverse effects on the solvent or operations due to other impurities in the flue gas were observed for some slight accumulation of hydrocarbons. The fact that the main hydrocarbon in flue gas is methane may be the reason for the above.

The organic acid HSS concentration in the solvent tended to increase in proportion to the operating time. This was as expected from the oxygen concentration in the flue gas, and no abnormalities were observed in the rate of increase.

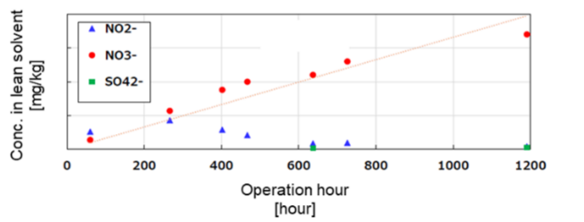

Figure 3. Inorganic ions accumulation in lean solvent

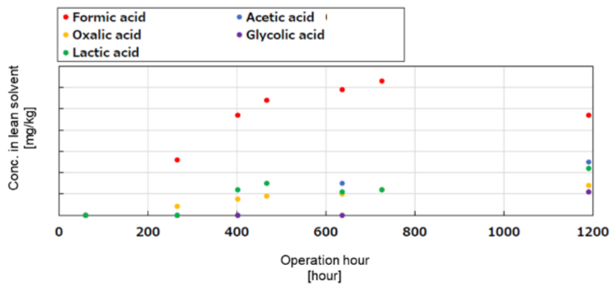

Figure 4. Organic acid accumulation in lean solvent

2.4.3 Quality of captured CO_2

Various impurities in the captured CO_2 were measured during the mobile testing campaign. Hydrocarbons were of particular concern as impurities in the captured CO_2 from gas engine flue gases. Light hydrocarbons may contaminate the captured CO_2. Other impurities such as oxygen, nitrogen, were observed to be no big different from flue gases other than gas engine. The measurement confirmed that the hydrocarbon content of the CO_2 meets the quality required by CCS in the United Kingdom, European Union, and the United States. Please note that, as with other flue gases, it may be necessary to install the unit to purify the CO_2 depending on the required CO_2 specification.

2.4.4 Technical items not verified in the mobile unit

There are other factors to consider besides the chemical and engineering compatibility between the flue gas conditions and the solvent verified in the mobile unit. For example, large fluctuations in gas flow rate and/or back pressure that may occur in the exhaust line of a gas engine should be considered in commercial implementation. However, these would be sufficient in applications from CO_2 capture from industrial facilities other than the gas engine.

3. Conclusion

The mobile test campaign for gas engines confirmed that there are no notable technical challenges for commercialization. Gas engines are widely used in industry. Applying CCS to gas engines as an environmental measure should be an important option in the pursuit of net zero.

4. References and bibliography

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[2] Takashi, K and Yoshinori, K and Takahiko, E and Hiromitsu, N and Hiroshi, T and Takuya, H and Takahito, Y and Tatsuya, T 2013. GHGT-11 SO_3 impact on amine emission and emission reduction technology, *Energy Procedia*, 000–000